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METHOD FOR DETERMINING A NEGATIVE SEQUENCE COMPONENT

BACKGROUND OF THE INVENTION

[0001] The invention relates to determining properties of a negative sequence component of a space vector quantity in an electrical network.

[0002] A three-phase unbalanced network can be presented with the aid of three symmetrical three-phase components, i.e. the zero sequence system (ZSS), the positive sequence system (PSS) and the negative sequence system (NSS).

[0003] The negative sequence system is defined by means of negative sequence components of quantities in an electrical network. Negative sequence components of quantities can be utilized in monitoring and controlling the electrical network.

BRIEF DESCRIPTION OF THE INVENTION

[0004] An object of the invention is to provide a method for determining properties of a negative sequence component of a space vector quantity in an electrical network. This object is achieved with a method that is characterized by what is stated in the independent claim. Preferred embodiments of the invention are described in the dependent claims.

[0005] The method according to the invention for determining properties of a negative sequence component of a space vector quantity in an electrical network can be utilized with compensation methods of voltage unbalance in an electrical network, for example.

[0006] The invention is based on determining the properties of the negative sequence component of a space vector quantity in an electrical network on the basis of the properties of an ellipse formed by a space vector of the space vector quantity in the electrical network.

BRIEF DESCRIPTION OF THE FIGURES

[0007] The invention will now be described in greater detail in connection with preferred embodiments, with reference to the attached drawings, of which:

Figure 1 shows circular graphs drawn by the tips of space vectors of the positive sequence and negative sequence systems, and an elliptical graphs drawn by the tip of a sum vector;

Figure 2 shows a block diagram for determining the components of the semi-axes of an ellipse formed by a voltage space vector in an electrical network; and

Figure 3 shows a block diagram for determining the magnitude of the negative sequence component of the voltage in an electrical network and the angle of the minor semi-axis of the voltage ellipse.

DETAILED DESCRIPTION OF THE INVENTION

[0008] The space vector quantity of an electrical network the properties of whose negative sequence component can be determined by means of the method according to the invention may be, for example, voltage or current. Below, there is an example where the properties of the negative sequence component are determined for the voltage of an electrical network.

[0009] If no zero sequence component occurs in the electrical network, the total voltage is the sum of the negative sequence and the positive sequence components, in which case the graph of the voltage vector $\underline{u}_2$ in the network is an ellipse in accordance with Figure 1, and the voltage vector in question can be determined with the following equation:

$$\underline{u}_2 = u_{2,PSS} e^{j\omega t} + u_{2,NSS} e^{-j(\omega t - \phi)},$$

where $u_{2,PSS}$ is the magnitude of the positive sequence component of the voltage in the electrical network, $u_{2,NSS}$ is the magnitude of the negative sequence component of the voltage in the electrical network, ω is the angular frequency, t is time, and Φ is the phase-angle difference between the positive sequence and negative sequence systems at starting time. At the major semi-axis of the ellipse the angles of the positive and negative sequence system vectors are the same, so that the angle of the major semi-axis is

$$\alpha_{maj} = \phi / 2 + n\pi .$$

[0010] The length l_{maj} of the major semi-axis of the ellipse is the sum of the length $u_{2,PSS}$ of the positive sequence vector and the length $u_{2,NSS}$ of the negative sequence vector of the voltage. The minor semi-axis of the ellipse is perpendicular relative to the major semi-axis, so that its angle is

$$\alpha_{\min} = \phi / 2 - \pi / 2 + n\pi .$$

[0011] The length l_{min} of the minor semi-axis is the difference between the length $u_{2,PSS}$ of the positive sequence vector and the length $u_{2,NSS}$ of the negative sequence vector of the voltage. The length $u_{2,PSS}$ of the positive sequence vector of the voltage is received by dividing the sum of the length l_{maj} of the major semi-axis and the length l_{min} of the minor semi-axis by two.

$$u_{2,PSS} = \frac{l_{maj} + l_{\min}}{2}$$

[0012] Correspondingly, the length $u_{2,NSS}$ of the negative sequence vector of the voltage is received by dividing the difference between the length l_{maj} of the major semi-axis and the length l_{min} of the minor semi-axis by two.

$$u_{2,NSS} = \frac{l_{maj} - l_{\min}}{2}$$

[0013] On the basis of the above, the magnitudes of the positive sequence and negative sequence system components can be deduced from the lengths of the semi-axes of the ellipse. As noted above, the phase-angle difference between the positive sequence and negative sequence systems at starting time can be deduced from the angle of the major semi-axis of the ellipse. Thus, determining the negative sequence network can be returned to determining the properties of the sum voltage ellipse.

[0014] Figure 2 shows one way to determine components $u_{2\alpha,maj}$, $u_{2\beta,maj}$, $u_{2\alpha,min}$ and $u_{2\beta,min}$ of the major and minor semi-axes of the ellipse formed by the voltage space vector in the electrical network. The voltage vector components $u_{2\alpha}$ and $u_{2\beta}$ of the electrical network that have been measured first are low-pass-filtered in such a way that only a fundamental wave remains. The purpose of the low-pass filtering is to remove the harmonic components. The filter type is not restricted in any way, and the phase errors caused by the filters do not affect the functioning of the method.

[0015] In practice, there is no need to filter out the harmonic waves of the voltage vector components $u_{2\alpha}$ and $u_{2\beta}$ quite completely, but it suffices to reduce their number to a predetermined level. Thus, in some cases low-pass filtering may not be needed at all.

[0016] In the procedure shown in Figure 2, the axes of the ellipse are determined by recognizing the extreme value points of the length $|\underline{u}_{2f}|$ of

the fundamental wave voltage vector. The extreme value points are determined with a simple derivative test, which can be presented as a discreet algorithm below, where k is the time index and T_S is the sampling period.

1. Compute the length $|\underline{u}_{2f}|$ of the fundamental wave vector of the voltage.
2. Approximate the derivative with difference $d_k = (|\underline{u}_{2f}|_k - |\underline{u}_{2f}|_{k-1}) / T_S$.
3. Check the extreme value conditions.
   - If $d_k < 0$ and $d_{k-1} > 0$, a maximum (major semi-axis) is concerned.
   - If $d_k > 0$ and $d_{k-1} < 0$, a minimum (minor semi-axis) is concerned.
4. If a maximum or minimum was found, store the current $u_{2\alpha f,k}$ and $u_{2\beta f,k}$, depending on the type of the extreme value, as components of vector $\underline{u}_{2,maj}$ or $\underline{u}_{2,min}$.

[0017] The classification of the extreme values on the basis of the zeros of the derivative signal, taking place at point 3 in the algorithm, is analogous with the classification of extreme values of continuous functions based on the sign of the second derivative. In the practical implementation at point 1, the quadratic length of the fundamental wave vector can be used, because the square root as a monotonic function does not affect the extreme values. Further, at point 2 the difference quotient can be replaced with the difference by omitting the division by the sampling period T_S.

[0018] When the above-described algorithm is used, the sampling period T_S may be 100μs, for example. At point 4 of the algorithm, the number of values $u_{2\alpha f,k}$ and $u_{2\beta f,k}$ to be stored can, if desired, be halved by storing only the semi-axis components that are located at the left half-plane, for example.

[0019] Determination of the components of the semi-axes of the ellipse is the only time-critical stage in measuring the negative sequence system. The other stages may be implemented at slower time planes, for instance at a time plane of 1 ms. The lengths l_{maj} and l_{min} of the semi-axes of the voltage ellipse are computed by means of determined components with the following equations:

$$l_{maj} = \sqrt{u_{2\alpha,maj}^2 + u_{2\beta,maj}^2} \quad \text{and}$$

$$l_{\min} = \sqrt{u_{2\alpha,\min}^2 + u_{2\beta,\min}^2} \quad .$$

[0020] The magnitudes $u_{2,PSS}$ and $u_{2,NSS}$ of the positive sequence and negative sequence components can be computed by means of the lengths l_{maj} and l_{min} of the semi-axes of the ellipse with the above-described equation. The following equation yields the angle α_{min} of the minor semi-axis of the ellipse:

$$\alpha_{\min} = \arctan\left(\frac{u_{2\beta,\min}}{u_{2\alpha,\min}}\right).$$

[0021] One way to determine the length $u_{2,NSS}$ of the negative sequence vector of the voltage in the electrical network and the angle α_{min} of the minor semi-axis of the voltage ellipse is shown in Figure 3. The output information of the block diagram of Figure 2, i.e. the components of the major and minor semi-axes of the ellipse formed by the voltage space vector in the electrical network, is fed to the input of the block diagram of Figure 3.

[0022] Above, the ellipse formed by a voltage space vector in an electrical network is assumed to be of a shape of a complete ellipse, known from the theory of mathematics. In practice, the ellipse formed by a voltage space vector in an electrical network is always somewhat deformed, but it is obvious that this does not in any way prevent the use of the method according to the invention, because with an appropriate algorithm, the location of the semi-axes can be determined even from an incomplete ellipse. There are several known algorithms applicable to the determination of the semi-axes of incomplete ellipses, and the method according to the invention does not impose restrictions on the algorithm to be used.

[0023] In the above example, the method according to the invention is used for determining properties of a negative sequence component of the voltage in an electrical network. It will be obvious to a person skilled in the art that the method according to the invention can also be used for determining properties of a negative sequence component of other space vector quantities, such as current.

[0024] Above, the method according to the invention is used in a case where there is no zero sequence component in the electrical network. Although the presented method is based on measuring a space vector of a space vector quantity where a zero sequence component is not seen in any way, it is clear that the method according to the invention can be used for

determining also such space vector quantities in electrical networks where the zero sequence component occurs.

[0025] It will be obvious to a person skilled in the art that the basic idea of the invention can be implemented in a plurality of ways. Thus, the invention and its embodiments are not restricted to the above examples but may vary within the scope of the claims.